Kinetic and isotope ratios temperatures: a comparison

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Temperature measurements in heavy-ion reactions have been discussed at length following the experimental results of Pochodzalla *et al.* [1]. Three different methods are generally used to extract nuclear temperatures (see [2] for a review of the first two): 1) the slope of the kinetic energy spectra; 2) the population of excited states; and 3) the double ratio of isotope yields [3]. A detailed comparison of these methods within a sequential model by Siwek et al. [4] has shown that temperatures extracted from the kinetic energy spectra are the closest to the initial temperatures, if there is only one emission source with little collective energy. These two conditions are rarely met in intermediate energy heavy ion collisions.

An experiment to compare temperatures from isotope ratios and kinetic energy spectra was performed at the LBNL 88" cyclotron. High statistic evaporation spectra of hydrogen and helium isotopes from compound nuclei were measured in the reaction ^{12}C+^{nat}Ag at 102 MeV. The set-up consisted of 6 Si-Si(li) ΔE-E telescopes placed at backward angles of 122.5^o, 135^o and 147.5^o in the lab frame. The energy spectra were transformed from the laboratory to the center-of-mass (CM) frame assuming the compound nucleus velocity along the beam axis. Each spectrum was then fitted using Moretto's formalism [5] from which a barrier and temperature were extracted.

CM energy spectra at 135^o are shown in the top panel of Fig. 1 as a function of the energy relative to the Coulomb barrier. It can be immediately seen that the slope of the ^{4}He distribution, T_s=3.0 MeV, is steeper than for the ^{3}He, T_s=3.8 MeV, making the ratio of the two isotopes dependent on the kinetic energy. On the other hand, ^{2}H and ^{3}H isotopes have more comparable slopes, 3.3 MeV vs 3.6 MeV, making their ratio about constant. While ^{4}He (like the proton) has a small emission Q_{value}, ^{2}H, ^{3}H and ^{3}He have a large Q_{value}, around -12 MeV for first chance emission. Thus, ^{2}H, ^{3}H and ^{3}He tend to be emitted early in the decay chain. This behavior is strikingly similar to that observed in intermediate energy heavy-ion reactions [6,7].

Assuming thermal and chemical equilibrium, the temperature can also be obtained from the double ratio of isotope yields for nuclei formed in the ground states [3]

$$T_{HHe} = \frac{14.3MeV}{ln[1.60 \times \frac{Y(^4He)/Y(^3He)}{Y(^3H)/Y(^2H)}]}. \tag{1}$$

Integrating the yields over all kinetic energies, T_{HHE} is equal to 2.4 MeV, shown by the dashed line in Fig. 1 (bottom panel). This value is in good agreement with the Fermi gas temperature, also 2.4 MeV, obtained from the excitation energy assuming $a = A/8$ MeV^{-1} for the level density parameter. However T_{HHe} depends strongly on the kinetic energy because of the ^{4}He/^{3}He ratio. The open symbols in the bottom panel of Fig. 1 give the evolution of the isotope ratio thermometer calculated at various energies $E - B_c$. As for the intermediate energy heavy-ion reactions, it is tempting to interpret the change in T_{HHe} as evidence for time dependent evaporative cooling of the hot residues [7,8]. The highest temperatures are associated with the early stage of the decay chain that are probed by T_{HHe} at high kinetic energies with the time increasing as the kinetic energy decreases.

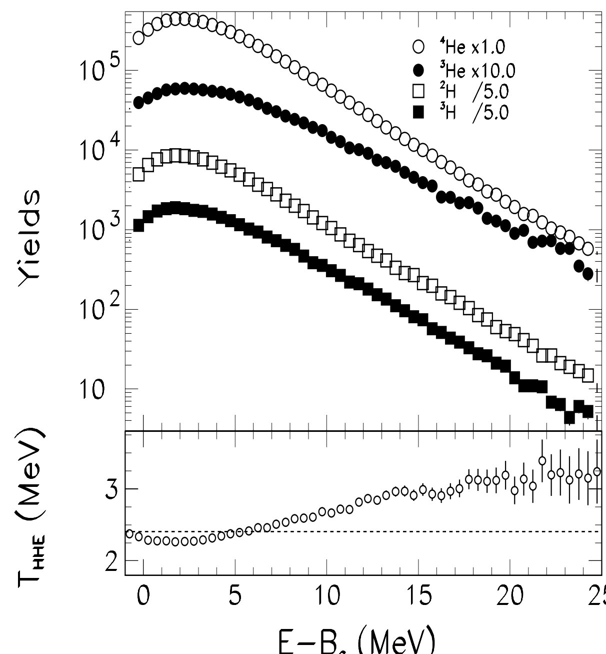

FIG. 1. Top panel: ^{2}H, ^{3}H, ^{3}He and ^{4}He kinetic energy spectra in the CM frame adjusted by their respective Coulomb barriers. Bottom panel: Temperature from the double ratio of isotope yields as function of kinetic energy relative to the Coulomb barrier. The dashed line corresponds to the temperature when the yields are integrated over all kinetic energies.

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